Geoderma, 32 (1984) 297—317
Elsevier Science Publishers B.V., Amsterdam — Printed in The Netherlands

DEVELOPMENT AND USE OF SOIL PRODUCTIVITY RATINGS IN THE UNITED STATES*

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(Received April 26, 1983; revised version accepted October 27, 1983)

ABSTRACT

Huddleston, J.H., 1984. Development and use of soil productivity ratings in the United States. Geoderma, 32: 297—317.

This paper provides historical documentation of major U.S. efforts to develop numerical ratings of soil productivity. Nearly all of these efforts stemmed from needs to compare different soils objectively for purposes of agricultural land use planning and the equalization of land values and tax assessments.

Several approaches are described, including U.S.D.A. work following World War I, ratings based solely on crop yield data, Storie's (1933, 1937, 1976) multiplicative factor approaches and the variations that evolved from them, and "Soil property systems" that add, rather than multiply, effects of separate factors. Taken together, these various approaches highlight a large number of soil properties, weather conditions, and crop yield data that need to be considered to develop ratings of soil productivity. They illustrate a variety of techniques for evaluating the effects of soil properties quantitatively and for combining soil factor values into overall soil ratings. Each approach has certain advantages and limitations, and these are discussed throughout. The collective experiences with the development and use of productivity ratings cover a diversity of soil and climatic conditions throughout the United States.

INTRODUCTION

Soil productivity ratings can be expressed either qualitatively or quantitatively. Qualitative ratings may be as simple as narrative statements of soil suitability for particular crops, or they may group soils subjectively into a small number of classes or grades of agricultural suitability. Both kinds of qualitative ratings were used widely in early soil survey work in the United States.

Quantitative expression of soil productivity may be done inductively or deductively (Ableiter, 1937). Inductive productivity ratings are derived solely from the inferred effects of various soil and land properties on the yield potential of a soil. Crop yield data are not used directly in the calculation of productivity indexes. Deductive productivity ratings, on the other hand, are based entirely on records of crop yields obtained from different soils.

*Technical paper no.6751 of the Oregon Agricultural Experiment Station.

0016-7061/84/$03.00

Most productivity evaluations actually combine elements of both inductive and deductive reasoning. Even qualitative ratings are done with some knowledge of probable crop yields, and most of the predominantly inductive approaches use crop yield data in some way to develop or calibrate the ratings. Conversely, deductive ratings can be made only for a few crops on a few soils, so that extension to other soils necessarily requires inductive thinking. Further, some productivity ratings based solely on yield data employ inductive reasoning to derive empirical ratings of productivity that are not crop yields per se. Thus productivity evaluation in the United States has involved a blend of qualitative and quantitative ratings, as well as inductive and deductive processes.

The original use of qualitative productivity evaluations was to help farmers select crops and management practices best adapted to the soil resources of their farms. This is still an important use of yield-based productivity ratings. Quantitative ratings were first developed to help distinguish between highly productive soils to keep in agricultural use and less productive soils to remove from production. Inequities in the tax assessment of agricultural land also led to several efforts to develop objective ways of determining the true value of a soil for agricultural production, and hence, equalize tax rates. In the last few years productivity ratings have been used to help make choices among several competing land uses.

EARLY WORK BY THE U.S. DEPARTMENT OF AGRICULTURE

The Division of Soils was established in 1894 under the jurisdiction of the U.S.D.A. Weather Bureau specifically to study soil moisture and temperature conditions in some of the most important types of soil in the country (Whitney, 1894). Milton Whitney was the Director of this new Division, and he was keenly aware that soils were different from place to place and that differences in soil properties influenced both the kinds of crops best adapted and the amount and quality of crop yields. Under his leadership, therefore, the Division of Soils quickly gave the study of moisture and temperature low priority in favor of more practical soil survey work of immediate benefit to farmers (Whitney, 1904).

Qualitative ratings used in early soil surveys

In 1901 the Division of Soils became an independent agency within U.S.D.A. and was renamed the Bureau of Soils. The basic premise of the Bureau's program was that differences in the commercial value of agricultural land could be detected in the field, based on soil properties such as texture and structure, and on their relationships to crop adaptability (Whitney, 1904). Soil maps could be made to show these differences, so that farmers or land buyers could quickly and easily assess the farming value of a tract of land. Evaluation of soil productivity was, in fact, the primary reason for the initiation of soil surveys in the United States.

Qualitative evaluations of soil productivity in relation to crop yield remained the primary focus of the Bureau of Soils until the early 30's. Jay Bonsteel (1911), for example, prepared some 40 publications, each describing the characteristics, general productivity, crop adaptability and estimated yields for a specific soil type. Throughout this period, soil surveys continued to provide American farmers with "definite knowledge . . . regarding . . . present and potential productiveness [of soils], the type of agriculture for which they are best suited, methods of soil improvement, crop adaptation, and their proper management" (Jardine, 1927).

The first qualitative classification of soil productivity was Whitney's (1909) grouping of the soils of the U.S. into three agricultural ranks plus a non-agricultural group. He recognized that actual yields depend on management and economic factors as well as soils, and tried specifically to rate soils on their potential, regardless of present use. No specific criteria for determining the rank of a soil were given, and the system does not appear at all in subsequent revisions of Whitney's original bulletin (Marbut et al., 1913; Whitney, 1911).

Quantitative ratings developed by the Bureau of Chemistry and Soils

Soon after World War I, U.S.D.A. began to deemphasize soil productivity in favor of broader systems of land classification. Surplus production of farm crops created a need for agricultural readjustment through more complete use of productive soils, less intensive use of marginal lands, and better adjustment of crops to soil conditions (Knight, 1931). Lipman (1932) specifically recommended: (1) a national inventory of soil and land resources; (2) a national policy for erosion control; (3) eliminating from production all unprofitable lands; (4) taxing land according to inherent productive capacity; (5) tailoring farming systems to the soil and climatic conditions of a region; (6) intensifying production on the better soils; and (7) providing information on inherent productivity, crop adaptability, erodibility, and present and potential returns for each soil type mapped.

In 1931, U.S.D.A. set up a National Land Use Planning Committee specifically to address the roles of land classification in agricultural readjustment. Three years later the National Resources Board was created with a mandate to prepare a report on the nation's land and water resources (National Resources Board, 1934). The NRB in turn requested U.S.D.A. to provide an inventory of the physical assets of the country (Ableiter, 1940). U.S.D.A.'s response was to develop one of the first numerical systems for rating soil productivity (Ableiter, 1940; Knight, 1934). At the time of the NRB request, Dr. C.F. Marbut was Chief of the Soil Survey Division in the Bureau of Chemistry and Soils. He immediately asked soil scientists in each of the State Agricultural Experiment Stations to provide information on their soils for compilation into a national rating (Ableiter, 1937, 1940; Brown et al., 1936). C.P. Barnes, of the Agricultural Adjustment Administration's Land

Policy Section, worked very closely with Marbut in the development of nationwide soil productivity ratings (Ableiter, 1940).

The objective of this effort was to rate the "inherent" productivity of a soil, under the assumption that it represented the most stable attribute of land, unaffected by non-land inputs that influence crop yields (Barnes, 1935a; Marbut, 1935). "Inherent" did not mean totally unmanaged, but it did limit fertility management to the addition of manure and crop residues necessary to maintain productivity. Artificial drainage of wet soils and flood protection for flood-prone soils were also permitted management practices.

For each of a number of major crops, Marbut (1935) and Barnes (1935b) assigned the best soil in the U.S. a rating of 10. Characteristics of that soil were carefully recorded, and all other soils were rated between 1 and 10 by comparing their characteristics with those of the best soil. Statistics on crop production were not used directly to make these ratings. Productivity ratings for the individual crops were then combined into an overall rating, called the productivity grade. Grades of soil productivity also ranged from 1 to 10, but the best soil was grade 1, rather than grade 10.

U.S.D.A. productivity ratings did accomplish the objective of inventorying the relative productivity of the nation's soil resources (Barnes, 1935b). The greatest weakness in the system, however, was the lack of specific criteria, at least in published form, for comparing soil characteristics and determining soil ratings. Apparently a considerable amount of subjective judgment was required. Similarly, no specific criteria for combining ratings to determine productivity grades were published, except that staple crops were given more weight.

Despite these limitations, this approach was adopted, with some modifications, to develop productivity ratings for soils in Maryland (Bruce and Metzger, 1933), North Carolina (Williams et al., 1934), Iowa (Brown et al., 1936), Oregon (Powers et al., 1939) and Ohio (Conrey and Paschall, 1934). Conrey (1935) used the Ohio ratings for corn to determine the proper yield to use for land appraisal purposes. Productivity ratings and productivity grades also were included in U.S.D.A. soil survey reports published in the mid-1930's.

Modifications of the original system were being developed even as the earliest applications were being published. One change assigned a value of 100 to the best soils of the U.S. on which a particular crop was principally grown. All other soils were rated as a percentage of the best according to their relative yields. This change was accompanied by increasing recognition of the need for more yield data to test ratings that were based primarily on soil characteristics (Ableiter, 1937, 1940; Barnes, 1935a).

Another change shifted the emphasis from "inherent" productivity to productivity that could be achieved by better-than-average farmers using current technology (Ableiter, 1937). A third change based the calculation of productivity grades on the relative proportions of land used for each individual crop for which a soil was rated (Ableiter, 1937, 1940).

Several states adopted this newer approach, but with modifications, to solve specific land use problems. In North Dakota, productivity ratings were used to calculate overall agricultural land ratings for each 40-acre tract in a taxing district (Kellogg, 1935; Kellogg and Ableiter, 1935; Tyner and Steele, 1937). Productivity ratings, however, were expressed as a percentage of the best soil in the *county*, and they were adjusted according to various economic, social, and geographic factors to arrive at a final land rating. Fitzpatrick (1937) developed similar general soil ratings for a county in Oklahoma. He also used a county standard, but his general rating was simply the arithmetic average of four specific crop ratings. Anderson et al. (1938) calculated ratings as percentages of county standard yields in Nebraska but placed much more emphasis than before on the effects of slope and erosion on soil productivity.

From 1935—1940, most U.S.D.A. soil survey reports tabulated productivity ratings for each major crop expressed as a percentage of a national standard. After 1940, however, their use declined rapidly. In large measure, this was due to increasing recognition of the desirability of assembling crop yield data for soil types rather than continuing to make judgments of potential productivity based primarily on soil properties. Other factors that may have had some impact were the passing of the agricultural adjustment crisis and increasing attention in the soil survey to soil genesis and classification. At any rate, U.S.D.A. did not use soil productivity ratings much after 1938, and their appearance in soil surveys published as late as 1950 represents largely a lag in work that had been initiated before 1940. By the time "modern" soil surveys began appearing in the late 1950's, productivity ratings were no longer being used, having been replaced entirely by tables of estimated yields.

DEDUCTIVE RATINGS BASED ON CROP YIELD DATA

Purely deductive ratings of soil productivity are based entirely on crop yield data (Ableiter, 1937). No specific consideration is given to the effects of various soil properties on plant growth and yield. Two approaches to deductive yield-based ratings have been taken. One is to simply prepare tables of average yields or estimated yields for the common crops on the major soils of an area. The other manipulates crop yield data in various ways to derive an empirical productivity index. Both approaches acquire yield data from the same sources (Ableiter and Barnes, 1950; Rust and Odell, 1957): detailed farm records, experimental data from research plots and farm fields, and the obervations and judgments of farmers and other knowledgeable agriculturalists.

Advantages and limitations

The most significant advantage of crop yield productivity ratings is the expression of productivity in absolute rather than relative terms. Use of yield data also removes the necessity for subjective interpretations of soil properties by skilled soil scientists (Ableiter, 1937).

The most serious limitation of yield-based productivity ratings is the lack of enough reliable yield data. Even where data records are fairly extensive, as in Iowa (Fenton et al., 1971) and Illinois (Odell and Smith, 1940), crop yields are available only for a few principal crops on the major soils of the state. Yield information on other crops, other soils, or other than the main phases of soil series must be obtained by inference from soil conditions, by estimation from knowledgeable sources, or by a combination of the two.

Other limitations arise because yields depend not only on soil characteristics, but also on vagaries of the weather, differences among soils in a given field, management skills of farm operators, and the level of current technology. As a result, the use of long-term average yields to express productivity has limited value for a specific soil in a specific location for a specific year.

Several solutions to these limitations have been proposed. Some authors (North Central Regional Tech. Comm. 3, 1965; Odell and Smith, 1940; Rust and Hanson, 1975) address the management question by giving estimated yields for two or three different levels of management. Others (Bell et al., 1981; Bone and Norton, 1981; Gray et al., 1979; Malo and Westin, 1978) give yields for only one level of management but specify the management practices necessary to achieve these expectations. Murray et al. (1939) held management constant by determining yields from different soils in the same field.

The technology question has been handled by updating yield estimates every five years or so (Fehrenbacher et al., 1978; Rust and Hanson, 1975; Bell et al., 1981) or by converting yield data into empirical indexes such that the productivity of one soil relative to another does not change, even though absolute yields do (Bone and Norton, 1981; Malo and Westin, 1978).

The problem of soil differences within fields was dealt with most effectively in Illinois (Odell and Smith, 1940). Data were obtained from long-term farm records, but great care was taken to use data only from fields in which 90% or more of the soil was in fact the soil shown on the soil survey, and the remaining 10% was of similar productivity.

Ranges inherent in the defined span of a soil series present another problem. Yield estimates are reasonably reliable as long as the series is narrowly defined. Long-term averages are less useful for broadly defined soils or soils occurring over a wide geographic area. But narrowing the range means more soil types, and it is virtually impossible to acquire adequate yield data for every kind of soil (Smith and Smith, 1939). Thus, the deductive approach is limited to principal crops on major soils, and inductive processes are required to derive productivity ratings for other soils.

Because of the limitations on the acquisition and validity of crop yield data, most authors who have published tables of crop yields for soils of their areas have used a combination of deductive and inductive processes. The most comprehensive studies of this kind have been done in Ohio (Bone and

Norton, 1981), Iowa (Fenton et al., 1971), Illinois (Fehrenbacher et al., 1978), and Tennessee (Buntley and Bell, 1976; Bell et al., 1981). In each case, research data and farm records were used to establish long-term average yields for a few crops on the major soils. Estimated yields for other soils were made by comparing soil properties with those of the benchmark soils. In Ohio and Illinois, yields were published only for the dominant phase of a series, but criteria for adjusting yields according to differences in slope and erosion were provided. In Iowa and Tennessee, estimated yields were given for all phases of soil series on which the principal crops were grown.

Applications of crop yield data

For many years, equitable assessment of farmland has been one of the main reasons for compiling yield data as measures of soil productivity. Halcrow and Stucky (1949) classified Montana soils into grades of productivity based on yield estimates, then calculated average productivity grades for each 40-acre tract as a basis for tax-equalization. Lindsey (1950) calculated a net income for each productivity class of Nebraska soils using average yields, prices from a base period, and estimated costs of production. He derived land values by capitalizing net incomes at prevailing interest rates and adjusting for the quality of roads serving a particular tract of land. Foss et al. (1971) used a similar procedure to determine land values for each township in each county of North Dakota.

Another use of yield data has been to help farmers determine realistic productivity levels under specified kinds of management systems. This was one of the principal reasons for publication of yield data under both average and high management levels for the north central states (North Central Regional Tech. Comm. 3, 1965). It was also a major reason for including tables of estimated yields in U.S.D.A. Soil Survey Reports published since the early 1940's. Many of the early reports included estimated yields for two, and occasionally three, levels of management. Since the late 1970's, however, estimated yields in soil survey reports have been given for only a single, high level of soil management.

Given the limitations associated with yield data, perhaps the best use, and the greatest need for good yield data, has been to develop and calibrate inductively derived productivity ratings. For most applications, absolute values of expected yields are less important than relative comparisons of yield potentials among soils. Indexes of relative yield are much less subject to temporal variability due to management, technology, or weather, although it is essential that indexes derived from inductive approaches provide realistic comparisons of yield potentials. Odell and Smith (1940) concluded that long-term yield averages could be used safely to calibrate productivity ratings, and indeed investigators in Ohio, Iowa, and Illinois who published extensive yield data did so only in conjunction with the publication of relative productivity ratings derived either from the yield data themselves or from inductive systems based on soil properties.

Empirical ratings based on crop yield data

The advantages of relative ratings over absolute yields led to some different ways of transforming yield data into productivity ratings. Englehorn (1936), for example, converted estimated yields for several crops to equivalent feed units, totaled the feed unit ratings for all crops in a rotation, and divided by the number of years in the rotation to derive an average annual feed unit as the productivity rating. The correlation between these ratings and assessed land values was only 0.58. Wright (1979) converted yields of all crops in a rotation to total digestible nutrients and scaled the results from 0 to 100. These ratings were combined with the land capability classification to establish soil value groups used in the assessment of agricultural land.

Odell and Oschwald (1970) assigned 30-year average yields from the more productive soils of Illinois an index of 100 and expressed all other yields as a percentage of the base. Then they calculated a grain crop index as a weighted average of all grain crop ratings. The weighting factors were the proportions of land devoted to each grain crop in each region of Illinois. Fehrenbacher et al. (1978) used these grain crop indexes to establish three classes of prime agricultural land in Illinois.

In South Dakota, all yields for a given crop were first expressed as a percentage of the maximum yield of that crop (Malo and Westin, 1978). Then a composite crop rating was determined for each soil as the simple arithmetic average of the ratings for all crops grown on that soil. The highest composite rating was set equal to 100, and all others were scaled appropriately to derive a final crop rating. Similarly, all soils were given a rating for rangeland productivity as the percent of the AUM productivity of the best soil. Range productivity ratings were brought into balance with crop productivity ratings through multiplying by a "balance point factor". This factor was calculated as the ratio of the average AUM rating for all class-IV soils to the average final crop rating for all class-IV soils. The ultimate rating assigned to a soil was either the final crop rating for soils in capability classes I—IV or the adjusted range rating for soils in capability classes V—VII.

Minnesota's crop equivalent rating (Rust and Hanson, 1975) is basically an index of net return from the major crops grown in rotation on a soil. For each crop, yields from long-term records were multiplied by a 5-year average price. Costs of production, both fixed (land, taxes, permanent improvements) and variable (seed, fertilizer, tillage, harvest), were subtracted from the gross return. The net was multiplied by the percent of the land area of that soil used for the crop, as indicated by the Conservation Needs Inventory. Proprotional net returns were then summed over all major crops grown on the soil. The highest sum was set equal to 100, and all others were expressed as a percentage of the highest. Crop equivalent ratings are used to calculate weighted average ratings for 40-acre tracts and to determine relationships with sales prices and tax values.

Bone and Norton (1981), after tabulating estimated yields for five major crops, then converted each yield to hundredweight, summed all five crops, and divided by the sum of the expected maximum yields. Under the high level of management which they assumed, the two soils with the highest productivity indexes are both very poorly drained. Had costs of managing those soils been incorporated into the index calculation, as in Minnesota, the results would likely have been different.

INDUCTIVE RATINGS DERIVED FROM SOIL PROPERTIES

Purely inductive ratings of soil productivity are based entirely on inferences about the effects of numerous soil properties and weather conditions, acting singly and in combination, on the growth and yield of plants. Data on crop yields generally are not used directly in the derivation of numerical ratings by these methods, though such data are often used indirectly to calibrate or test inductive approaches.

Inductive approaches may be additive, multiplicative, or a combination of the two. All have the advantage of providing a relative productivity rating, usually on a scale of 1—100, that remains fairly constant over time. All have the capability of generating comparative productivities for soils entirely lacking any records of crop yields. All, however, have the potential of producing meaningless numbers unless ratings are carefully checked against some records of actual yield performance.

Multiplicative systems

Multiplicative systems assign separate ratings to each of several properties or factors, then take the product of all factor ratings as the final soil rating. This approach has the advantage that any single factor that may stand out as the dominant limitation to productivity also controls the rating. A very droughty soil, for example, might have factor ratings of 100, 95, and 30, making the overall rating 29. Removal of the drought limitation with irrigation might raise the last factor to 80, thereby changing the overall rating to 76. Another advantage is that the overall rating can never turn out to be a negative number.

One disadvantage of the multiplicative system is that the overall rating may be considerably lower than the ratings for each one of the individual factors. A five-factor model, for example, might rate each factor at 90 out of 100, but the overall rating would be only 59. Another disadvantage is that unless the criteria for assigning points to factors are spelled out precisely, it may be impossible for people other than the author of the system to duplicate his ratings.

The first and most widely known effort to spell out specific, quantitative criteria for rating soil productivity inductively was developed by Storie (1933) at Berkeley. The original Storie Index was calculated by multiplying together separate ratings for profile morphology, surface soil texture, and modifying factors such as depth, drainage, or alkalinity.

The profile factor placed each soil into one of six groups according to the degree of soil development. Deep, slightly weathered soils on nearly level terrain, for example, were placed in Group I and given a rating of 95—100. Residual soils on hill slopes were placed in Group VI and given a rating of 20—70, depending on depth to bedrock.

The surface texture rating was intended to express the general effects of all those factors, such as soil porosity, permeability, and tilth, that are closely related to texture. Each textural class, including gravelly and stony soils, was given a specific rating, ranging from 100 for loam to 20—30 for gravelly sand.

Ratings of soil modifying conditions ranged from 100 for well drained soils to 10—40 for badly waterlogged soils, from 100 for alkali-free soils to 5—25 for strongly alkali-affected soils, and from 80—95 for moderately eroded soils to 30—80 for badly eroded soils. Other conditions that were rated included acidity (60—95), infertility (60—95), subsoil stratification (60—95), depth (50—70), and slope (20—80).

Storie's system was significant in 1933, and remains so today, because it established a conceptual framework for rating soil productivity numerically and objectively by consideration of soil and landscape properties. It was an important application of soil survey information, for soil surveys, supplemented by additional field observations of soil-modifying conditions, provided the sources of data needed to make the ratings. The fact that the approach still required several subjective interpretations by skilled soil scientists may have been viewed as an advantage rather than a limitation. Storie made it quite clear that the factor ratings he provided were to be taken as guides rather than absolute values and that the ratings were to be changed as soil scientists gained experience with the index. Similarly, the lack of specific correlations between index numbers and crop yield data was not an oversight. Storie may not have had many yield data to work with, but he very definitely drew upon his own experiences and those of several soil surveyors in California in relating indexes based on soil properties to observations of plant growth and yield.

Storie prepared several revisions of the original system over the next 40 years. The first, in 1937, singled out slope as a separate, fourth factor (Storie, 1937). The most recent version of the system (Storie, 1976) uses nine rather than six classes of soil profile development, revises slightly the values assigned to surface textures, rates six classes of slope, and specifies that other conditions to be rated include drainage, alkali, nutrient level, acidity, erosion, and microrelief. Several ratings are still in terms of narrow ranges of values, which gives local users some flexibility, but still requires the inputs of knowledgeable soil scientists.

Weir and Storie (1936) used the original system to rate every soil phase being used in the California soil survey program at the time. In addition to the numerical ratings, they formulated six grades of agricultural suitability. Excellent agricultural soils, those in Grade 1, had ratings of 80—100. Good agricultural soils rated 60—79. Fair soils rated 40—59, poor soils were 20—39, and very poor, essentially non-arable soils rated 10—19. Grade 6 soils, rated 0—9, were considered non-agricultural. Storie Index Ratings, and/or grades of agricultural suitability, have been part of the text of every soil survey report published in California since 1936.

Storie and Wieslander (1948) subsequently used the original concept in modified form to develop a soil rating for timber sites. Five factors, each rated separately, were multiplied together to derive the rating. Their factors included soil depth, permeability, chemical factors such as alkalinity and salinity, soil drainage and climate. As with both original and revised Storie systems, ranges of values were given for levels of each factor (e.g., moderate chemical effects rated from 20 to 80), but no criteria were given for determining a specific factor rating for a specific soil. Once determined, each overall timber site rating was placed into one of five general classes of timber site productivity.

The Storie system was used in only slightly modified form to rate the productivity of soils in Hawaii (Land Study Bureau, 1972). Five factors were each rated and multiplied together, four of them being the same ones that Storie (1937) used in his revised guidelines. The fifth factor was rainfall. Factor ratings were given as ranges of values, but several ranges overlapped. Final productivity ratings were grouped into five classes of overall productivity. The data suggest that the system was not sensitive to differences in soil productivity, for most of the 137 soils rated fell into the two lowest classes, and none fell into the highest class.

Additive systems

Soil scientists in Wisconsin (Berger et al., 1952), Iowa (Fenton et al., 1971), Indiana (Walker, 1976), and Oregon (Huddleston, 1982) have calculated productivity ratings from additive systems. In each case, several soil properties were assigned numerical values according to their inferred impact on plant growth. These numbers were either summed up, or they were subtracted from a maximum rating of 100 to derive a final rating. Most of these rating systems were not purely inductive, as crop yield data were used either directly or indirectly to establish standards of performance for calibration of ratings induced from soil factors.

Additive systems have the advantage of being able to incorporate information from more soil properties than multiplicative systems. Four or five factors seems to be a practical limit for multiplicative systems; otherwise most ratings are so low that the approach cannot distinguish small differences in productivity. Additive systems allow the consideration of many more criteria, both singly and in combination with the effects of other factors. Other advantages are that no single factor can have enough weight to unduly influence the final rating, and it is generally easier to specify criteria exactly for unambiguous determination of factor values and soil productivity ratings.

Limitations of additive systems stem from their complexity. As the number of factors evaluated increases, so does the difficulty in juggling factor ratings so that the final ratings derived for a number of soils are all realistic. The problem is complicated further if the ratings must account for productivity with respect to several different crops and a wide variety of climatic conditions. One possible effect is the calculation of negative ratings. As long as only one or two major factors limit productivity, additive systems can work very well. But when each of several factors can be severely limiting, the final sum can be negative. None of the authors of additive systems have acknowledged this problem, let alone proposed ways to interpret negative productivity ratings. Additive systems also may fail to indicate the true impact of a single factor that may be so limiting as to render the soil unproductive. Such factors can only be assigned 25 or 30 points because of the possibility of negative numbers. Yet a final rating of 70 or 75 would not suggest that overall productivity is very low.

The earliest purely additive system consisted of a scorecard developed by Berger et al. (1952) in Wisconsin. Their objective was to provide a planning tool for use by cannery company and loan agency field men. The scorecard allowed those men to evaluate the productive capacity of the soils in fields for which no soil survey information was available. With the scorecard, an agricultural worker could simply go to the area of interest, observe and sample the soil, assign point values according to specific criteria on the scorecard, and add up the points to get an overall rating for each field. The system assigned a value of 0 to the minimum tolerable level for each of 11 soil, land and climatic factors. More favorable conditions received positive scores, and less favorable or intolerable conditions received negative scores. Soil factors evaluated in the field included slope, stoniness, erosion, texture, wetness, depth, and color. Soil factors determined in the lab included pH, available P, and available K. The one climatic factor evaluated was length of growing season. The scorecard was used widely in Wisconsin for about 10 years by cannery companies seeking to determine which fields they should rent (F.D. Hole, personal communication, 1982).

Development of Corn Suitability Ratings for Iowa soils represents the first effort to rate soils of an entire state using a comprehensive additive system. Early work on corn suitability ratings (Riecken and Smith, 1949) resulted in a 1—10 rating scale, with 1 being the best. These ratings, however, were not based on good yield records, and were admittedly only expressions of relative suitabilities for growing a single crop, namely corn. Nevertheless they were used in initial efforts to base tax assessments of Iowa farmland on the productive capacities of the soils (Scholtes and Riecken, 1952).

The revised Corn Suitability Ratings system (Fenton et al., 1971) is much more thoroughly documented, both in terms of yield records and in terms of the criteria and assumptions used to establish the ratings. Yield data from extensive research projects and from detailed farm management records were used to estimate attainable corn yields under normal weather conditions on each soil in the state. Soils having high yield potentials that were capable of being row-cropped and were located where weather conditions in Iowa were most favorable were given a CSR of 100. All other soils were rated by comparing their yields with those on the best soil and deducting additional points for various soil and weather conditions that were more limiting. Corn Suitability Ratings are expected to remain more or less constant in relation to one another even though yields will change with technology and weather variations.

A unique feature of the Iowa System is the rating of soils according to weather conditions at the center of the soil association areas in which they occur. Rating adjustments are made for weather conditions elsewhere in an association area that are either more or less favorable than the norm, but Fenton et al. (1971) do not explain how those adjustments are made. Adjustments of ratings are also made for a number of limitations such as slope, erosion, wetness, depth, texture, precipitation, and parent materials. The guidelines for making these adjustments are quite specific, although it is still not possible to duplicate CSR calculations for many of the soils listed using only the published information. The guidelines, however, are very useful for illustrating the kind of logic necessary to combine information on several different soil properties into a single rating of soil productivity.

Corn Suitability Ratings are used in Iowa as the basis for the valuation and assessment of agricultural land (Fenton, 1975). Assessors in each county are given CSR's for each soil mapping unit used in the soil survey of that county, adjusted if necessary for weather conditions. From the county CSR's, a weighted average rating is calculated for each 40-acre tract in the county. Assessors may lower the ratings slightly to account for adverse impacts due to soil patterns, lack of drainage outlets, flood hazards, or features shown on soil maps with spot symbols. They may also raise the ratings for large tracts of nearly level land or land having irrigation potential. Final ratings for 40-acre tracts are then correlated with sale price data to establish dollar values for individual Corn Suitability Ratings.

Walker (1976) applied the concepts of the Iowa CSR calculation to the derivation of yield estimates for Indiana soils. As in Iowa, much of the motivation was to devise a scheme for equitable assessment of agricultural lands. Instead of using a dimensionless scale of productivity ratings, however, Walker established estimated corn yields for key index soils, then added or subtracted some number of bushels/acre, depending on how much various soil properties caused the yield to differ from that of the index soil. Walker's system accounted for effects due to texture, depth, restrictive layers, drainage, slope, erosion, organic matter, and base saturation, as well as certain interactions between factors. The system was designed to provide ratings for individual phases of soil series.

The productivity ratings were then combined with the costs for achieving yield potential of a soil to formulate a productivity index that represented the potential net return to a given soil resource (Yahner and Srinivasan, 1975). Proposed uses for this index included planning for optimum agricultural use and determining fair prices and tax assessments for parcels of rural land.

The most purely inductive scheme for rating soil productivity by additive methods was developed by the Southern Regional Technical Work-Planning Conference (1974). Soils with the highest potential for corn production were assigned a maximum rating of 100 points. Penalty points were deducted for limitations due to soil factors such as water holding capacity, fertility status, erosion, flooding, and impeded drainage. Fourteen soil properties were considered. The amount of the penalty increased as the severity of limitation imposed by each factor increased.

An important advantage of the system of the Southern Region is that the criteria for determining the ratings are precisely spelled out and simple to use. Given a soil profile description accompanied by routine laboratory data, anyone could work through the system and arrive at the same answer.

One disadvantage of this approach is that there is no attempt to calibrate the rating procedure with crop yield data. There is no way of knowing whether two soils having different productivity ratings have the same relative difference in corn yield. Another potential disadvantage is the possibility of arriving at negative ratings. For example, a soil with a hardpan at 45 cm on a 10% slope in an aridic ustic moisture regime would have a rating at least as low as −25, probably lower. Neither the significance of negative ratings nor a suggestion as to how to deal with them were discussed.

The most recent attempt to combine inductive and deductive reasoning in an additive system for rating soil productivity comes from Oregon (Huddleston, 1982). The nomenclature of classes in higher categories of Soil Taxonomy serves as the starting point for assigning numerical values to the inferred impacts of soil properties on productivity. A Pachic Ultic Argixeroll, for example, is given 100 points for being a Mollisol, −20 for droughtiness associated with xeric moisture, 0 for the argillic horizon, −10 for the acidity of the Ultic intergrade, and +5 for the overthickened Pachic epipedon. Further adjustments are made for properties such as drainage, coarse fragments, depth, subsoil acidity, slope, and growing season.

One significant feature of the Oregon approach is that not one but several ratings are provided for each soil phase. The first rating is derived from the natural properties of the soil. Then three separate ratings adjustments are given to indicate how many points may be added to compensate for the use of lime and fertilizer, installation of tile drainage, and irrigation. Two final scores are given, one for maximum dryland productivity and one for maximum irrigated productivity. Another important feature of the Oregon system is complete specification of the process for deriving all ratings and ratings adjustments.

Like the Iowa approach, this system uses yield data to calibrate the rating procedure. Calibration data were taken from estimated yield tables accompanying soil surveys in several counties. For each county, yields of the major crops were expressed as a percentage of the maximum yield for that crop.

For each soil that occurred in three or more counties, yield data for all crops in all counties were combined to give an overall index of yield potential. These numbers were then used as targets which were matched as closely as possible by the inductive rating method. Once calibrated, calculation of productivity ratings from taxonomic classes and soil properties was completed for many other soil phases for which few or no yield data were available.

Potential uses of Oregon productivity ratings include the same applications for establishing land prices and tax assessment rates that several others have adopted. In addition, the rating adjustments permit comparisons of the relative effects of soil management practices on productivity enhancement. Huddleston (1982) also proposes that weighted average productivity ratings for a parcel of land can be used effectively in the land use planning process as one important feature in deciding whether or not a particular parcel should be reserved for agricultural use or converted to other uses.

Combined methods

Combined methods for rating soil productivity utilize both additive and multiplicative procedures. Most combined methods use additive processes to derive single-factor ratings, then multiply single-factor ratings together to derive final soil ratings. One system, however, multiplies single-factor ratings for each horizon in a soil, then sums the products over all horizons to derive the final rating.

The major advantage of combined systems is the ability to incorporate information from several soil factors without minimizing the impact of one or two major limitations and without generating ratings that are unrealistically low or even negative. The major disadvantages are that the methods can be more complex than simple multiplicative systems, and the criteria for assigning points are not always spelled out.

Most of the combined methods were derived from Storie's original multiplicative concepts. Harris (1949), for example, rated basic land values in Arizona by multiplying ratings for three separate factors: soil, water, and climate. Unlike the Storie system, Harris identified water availability as one of the primary factors because of its importance in giving value to land. He determined the water factor rating by averaging a quantity rating and a quality rating, then multiplying by a time-of-availability rating. Graphs of rating values vs. acre-feet and total salt content provide the criteria for determination of quantity and quality factors. No criteria are provided for rating time of availability.

Harris (1949) combined all soil properties that influence land values into a single factor. Ratings of surface soil texture were averaged with subsoil ratings, then multiplied by depth and slope ratings to determine the overall soil factor rating. Numerical values for various surface and subsoil conditions are given, but Harris admits that they are based strictly on his own opinions. Graphs of ratings vs. depth and slope are used to determine values to complete the soil factor calculation. One additional graph of ratings vs. length of growing season provides information for evaluating the third factor, climate.

The Harris system is interesting because it illustrates how Storie's basic concepts can be modified to fit a different situation. It also illustrates a different kind of logic for incorporating more information by adding some ratings and multiplying others. The use of graphs to establish some of the factor ratings is also a new idea. Application of the system is limited by its failure to indicate precisely how some of the factor ratings are derived and by its failure to validate factor values and final ratings with yield data of any sort.

LeVee and Dregne (1951) also adopted the basic Storie system to rate the productive capacity of land in New Mexico strictly on the basis of physical characteristics. Their factors of soil profile, slope, erosion, and other limitations were very similar to those used in Storie's revised approach of 1937. The profile factor was evaluated by adding numerical ratings for the effects of surface texture, subsoil permeability, substratum permeability, and geologic materials. This sum was further adjusted to account for the effects of associated soil factors such as inherent fertility, lime or gypsum accumulations, horizon thickness, and gravel content. Adjustments were made by multiplying the raw score by a percentage rating. The adjusted soil factor rating was then multiplied by ratings for slope, erosion, and other limitations to derive the final land rating.

The New Mexico system has the distinct advantage that criteria for evaluating each factor are spelled out. There is no need for subjective judgments, which means that consistent, comparable land ratings can be made by all who use the system. Ratings are not correlated with crop yields, although the authors indicate that the values do agree with general observations of crop producing capacity. They acknowledge that revisions will be necessary as more information becomes available but emphasize that even if the ratings do not express actual conditions satisfactorily, the consistency provided remains a distinct advantage.

Another adaptation of the Storie system was developed in the Canadian province of Saskatchewan. It is significant in this review, however, both because it stems directly from Storie's work and because it involves an interesting approach that could be very useful for soil scientists contemplating development of their own productivity ratings. The original system, developed specifically for rural land assessment, rated land by multiplying values determined separately for three factors: soil profile, topography, and special features (Mitchell, 1940). The profile factor was evaluated additively by summing points for texture (up to 40), structure (up to 30), and fertility (up to 30). Topography classes were each assigned a narrow range of values (e.g., 90--100 for gently undulating topography). Ratings of special features were determined by adding points (up to 25 each) for climate, salinity, stoniness, and wind erosion.

Mitchell did not have enough crop yield data to test his system fully, but

Moss (1972) later used 30 years of accumulated wheat yield records to evaluate the earlier productivity ratings. He found poor overall agreement and concluded that the soil profile factor had been over-weighted, whereas cimatic effects had been underemphasized. The revised procedure of Moss formulated a final soil rating by adding, rather than multiplying separate ratings for soil profile, texture, and climate. His most important contribution, however, was his use of yield data to determine the relative importance of each factor.

By comparison of similar soil profiles and textures, Moss found that the range in yield due to climate was 10.5 bushels per acre. In similar fashion, he found the effect of texture was 8.0 bu./acre, and the effect of soil profile was 5.2 bu./acre. On a proportionate basis, the separate effects were 44% for climate (10.5 divided by 10.5 + 8.0 + 5.2), 34% for texture, and 22% for profile. Because of these relationships, and his observations of interactions between climate and texture, Moss decided to allocate 40 points to each of the factors of climate and texture and only 20 points for soil profile characteristics. No productivity ratings developed or used in the United States have used yield data in this way to determine the relative weighting of the component factors in the system.

A different kind of combined method was used by Pierce et al. (1983) to evaluate long-term changes in soil productivity due to erosion. Using concepts first postulated by Neill (1979) in Missouri, Pierce et al. evaluated productivity in terms of three major factors that affect the soil environment for root growth. The factors were bulk density, available water, and pH. For every individual horizon in a soil profile, each factor was rated as a proportion of its sufficiency for root growth. These ratings were multiplied together, and the product was then multiplied by a weighting factor based on the assumed rooting pattern in an ideal soil. The final productivity rating was calculated as the sum of the weighted factor products for all horizons in the profile.

Pierce's approach is designed to use information available in the Soils-5 and National Resource Inventory data bases of the Soil Conservation Service. Mathematical relationships between sufficiency and measured values of bulk density, available water, and pH are given so that other investigators can apply the approach. Testing of the system on several soils in southeastern Minnesota demonstrated a good relationship between yields of corn and productivity indexes. The approach quantifies the change in productivity of different soils as successive increments of soil are lost by erosion. Pierce et al. (1983) suggest that the approach can be used to characterize the vulnerability of a soil to productivity reduction and that soil loss tolerance rates could be more precisely determined with this information.

CONCLUSIONS

Productivity ratings derived from objective, numerical systems over the last 50 years have been very useful as indicators of the relative quality of soil resources for crop production. Ideas proposed by Marbut, Storie, and others provided the conceptual and logical framework that stimulated the development of systems modified to fit different soil, weather, and cropping conditions. All of the systems that have been developed are useful as examples of the kinds of information needed to evaluate soil productivity, the techniques used to integrate information from numerous factors into single ratings, and the advantages and disadvantages of various approaches.

No single approach has emerged as a universal approach that works well in all situations. Crop yields might be the preferred method of expressing productivity if crop yield data were available for all crop—soil combinations encountered. Such data are not available and are not likely to be in the near future. For this reason, empirical ratings derived from soil properties are widely preferred. All of the soils or mapping units of an area, including those of minor extent, can be included in ratings derived from soil properties. This is particularly advantageous when ratings are used for tax equalization or evaluation of land use alternatives. In these situations, absolute values often are less important than relative position of a soil on a uniform scale of quality. Even in the absence of complete yield data, however, most investigators agree that productivity ratings must reflect realistic expectations of differences in soil quality for crop production. Therefore, most of the empirical models incorporate crop yield data in some way to enhance the validity of the ratings produced.

Empirical ratings are less subject to variation than are crop yield records and tend to remain fairly constant, even though absolute values of yields change. Nevertheless, even empirical ratings are not permanent, and methods for the derivation of productivity ratings must be revised periodically as new information on soil behavior becomes available and as experience is acquired with the use of ratings to solve practical problems.

Work done to date suggests that an optimum approach for the derivation of soil productivity ratings would have the following characteristics:

(1) Assignment of numerical values to all soil properties, landscape characteristics, and weather conditions that influence plant growth and yield.

(2) Use of both additive and multiplicative processes to formulate factor ratings and combine factors into final productivity ratings.

(3) Use of available yield data, either directly or indirectly, to develop and validate the ratings.

(4) Precise specification of all criteria used to assign numerical values, derive factor ratings, and combine factors in the model.

Such a system could incorporate advantages of existing systems, eliminate certain disadvantages, and ensure consistent derivation of ratings by all users of a system.

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